DEVELOPING THIN FILM COMPOSITE MEMBRANES FOR ENGINEERED OSMOSIS PROCESSES

by

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A Thesis submitted in fulfilment for the degree of

Doctoral of Philosophy

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Jun 2015

Certificate of Authorship

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Soleyman Sahebi

Signature of Student: ______________________

Date: 28-06-2015

ACKNOWLEDGEMENTS

I wish to express my heartfelt gratitude for my mother Mrs Sara for whom my success and progress matter the most. Her encouragement and inspiration gave me strength throughout my entire life. She was mother and father for me and my siblings from the very moment of our childhood since my father passed away early. Nothing is enough to appreciate her young life she spent for me, my brother and sister. Then I would like to dedicate this thesis that I achieved through a great challenge to my dear mom. Without her sacrifices, I never could have reached this stage. I also dedicate my thesis to my father who passed away very early but through his hard work and wise planning, our family managed to overcome all challenges and financial hardship years after his passing.

This dissertation would not have been possible without the support and encouragement of my principal supervisor Dr. Ho Kyong Shon. I would like to express my deepest gratitude and appreciation to him. I would like also to thank my co-supervisor Dr. Sherub Phuntsho for his kind support and his wisdom during my study at UTS. I also would like to express my sincere appreciation to Prof. Chung Tai-Shung (Neal) who give me a training opportunity into his fascinating membrane research group and Dr Han Gang who worked with me during the time in the National University of Singapore (NUS). I have learned and benefited a lot from the training workshop and without this opportunity this thesis would not be possible.

I also would like to thank my friends and research group members at UTS who made this journey memorable. I want to thank Lura Chekli, Fouze Lotfi, Ibrahim El Saliby, Tahir Majeed, Jung Eun Kim, Yun Chul Woo, Myoung Jun Park and I also appreciate Dr.Leonard D. Tijing for his kind help during my study. I also thank my elder brother Mr Saeed Sahebi and dear friend Dr. Diako Ebrahimi for their support and encouragement during my thesis when I faced very hard, stressful and challenging moments. Their advice gave me the light and encouragement to maintain the momentum.

Finally, I thank my beloved fiancé Nasim for the pain she has had to endure during my absence and cope with this condition in order to support my study while she had an internship and was passing through a difficult period of her study. I would like also to thank Nasim's family, especially her mother Mrs. Ziba Hesami who has been like a loving mother and Mr Salimiaghdam, who been as a precious father to me. I also want to thank my brother in-law Dr. Chia Salimiaghdam for his support during the time I was away and busy with this study.

Last but not least, I would like to thank the University of Technology, Sydney for offering me APA scholarships for my PhD studies at UTS and later on NCEDA scholarship by the National Centre of Excellence in Desalination Australia.

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3. *Sherub Phuntsho, **Soleyman Sahebi**, Amit Chanan, Ho Kyong Shon.," Pressure assisted osmosis: overcoming limitations of osmotic equilibrium in forward osmosis process", IWA-WWC&E 2014 Portugal.

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**Publications made during the PhD candidature including articles not entirely related to the Thesis. *Articles related to the Thesis.

ABSTRACT

The high demand for clean water resources has generated substantial research interest in terms of sustainable and low energy water purification technologies such as forward osmosis (FO). Compared to other membrane based technologies, the FO process is less energy intensive. However, there are challenges that need solutions to enable the FO to compete with other technologies for desalination. Suitable draw solution and a proper membrane are required to overcome the FO process challenges. Enormous effort has been expended to find a new material and better membrane design in order to develop a novel FO membrane that can meet high performance demands in relation to water flux, salt rejection and mechanical strength. This is of particular importance for the newly introduced concept of pressure assisted osmosis (PAO). The objectives of this dissertation are to understand the fundamentals of the FO and PAO as a basis for fabricating a suitable membrane for the FO and PAO process.

In the first part of the work, PAO and its potential application to overcome the limitations of osmotic equilibrium in the FO process is investigated. One of the practical applications of the FO process is desalination for irrigation purposes through the means of hybrid desalination units such as fertiliser drawn forward osmosis (FDFO). The utilisation of PAO in FDFO desalination is assessed .By integrating the PAO process into the FDFO desalination unit, water flux can be generated beyond the point of osmotic equilibrium. As a result, diluted fertilizer as DS in the FDFO unit can be applied for direct fertigation without the need for an additional post-treatment process such as nanofiltration to recover the fertiliser draw solution (DS). Integration of the PAO process has proved to be very effective in

generating extra water flux. This can serve to reduce the capital costs since no separate post-treatment process such as the NF is necessary.

In the second part of the work, a thin film composite membrane for the FO and PAO process is fabricated through Polyethersulfone as a polymer materials base. Phase inversion in the precipitation bath and membrane formation mechanism of these polymers, both with and without backing fabric support, is investigated. The membrane chemical properties and hydrophilicity have been found to play a key role in the mass transfer of water flux during the FO process. Therefore, attention has been directed at increasing the hydrophilicity of the membrane through blending sulphonated materials. It has been found that sulphonation not only affects the membrane performance but also the membrane structure and morphology. Through sulphonation, porosity and hydrophilicity of the substrate increases while the finger like structure disappears. This leads one to suppose that the high water flux does not have a direct relationship with the finger like membrane structure. Regardless of membrane morphology, substrate hydrophilicity is the key to achieving a high performance membrane. Sulphonation has been found to have a tremendous effect on the physical and chemical properties of the membrane. While sulphonation dramatically increases the hydrophilicity of the substrate, it decreases the membrane mechanical strength. Due to higher hydrophilicity and lower ICP as a result of blending the sulphonation polymer, a membrane with better performance in terms of water flux and selectivity has been developed for the FO process.

In the last part of the work, a special thin film composite (TFC) flat sheet membrane on a backing fabric is developed for the PAO application. The newly developed concept of PAO has introduced a hydraulic pressure to the feed side to overcome osmotic equilibrium and the extraction of more water. Accordingly, under the PAO process, a membrane with considerable mechanical strength is required. A thin film composite membrane supported on woven mesh fabric is designed to specifically solve the problem by embedding a woven mesh fabric support. An earlier part of this study reveals that the mechanical stability and special physical properties of the support layer are critical for the PAO process.

LIST OF ABBREVIATIONS

AL-DS	:	Active layer – draw solution
AL-FS	:	Active layer - feed solution
AL	:	Active layer
BW	:	Brackish water
CA	:	Cellulose acetate
CTA	:	Cellulose triacetate
CP	:	Concentration polarization
DI	:	Deionized water
DS	:	Draw solution
ECP	:	External concentration polarization
FDFO	:	Fertilizer drawn forward osmosis
FO	:	Forward osmosis
FS	:	Feed solution
ICP	:	Internal concentration polarization
IP	:	Interfacial polymerization
LMH	:	$L/m^2/h$
MW	:	Molecular weight
NF	:	Nanofiltration
PA	:	Polyamide
PAI	:	Poly (amide-imide)
PAO	:	Pressure assisted osmosis
PBI	:	Polybenzimidazole
PES	:	Polyethersulfone
PRO	:	Pressure-retarded osmosis
PSf	:	Polysulfone
PWP	:	Pure water permeability
RO	:	Reverse osmosis
RSF	:	Reverse solute flux
SEM	:	Scanning electron microscope
SL	:	Support layer
SRSF	:	Specific reverse solute flux
SW	:	Sea water
TFC	:	Thin film composite
TFN	:	Thin film nanocomposite

LIST OF SYMBOLS

A	:	Water permeability coefficient (L .m^{-2} .h^{-1}.bar^{-1})
B	:	Salt permeability coefficient (m.s^{-1})
D/Ds	:	Diffusion coefficient (m^{2} s^{-1})
J_s	:	Solute flux (g.m^{-2}.h^{-1})
J_w	:	Water flux (L m^{-2} h^{-1})
k	:	Mass transfer coefficient
K	:	Solute diffusion resistance (s.m^{-1})
M	:	Molar concentration of the solution
Mw	:	Molecular weight (mol.g^{-1})
n	:	Van't Hoff factor
P	:	Applied hydraulic pressure (bar)
Re	:	Reynolds number
Sc	:	Schmidt number
Sh	:	Sherwood number
T	:	Absolute temperature (in K)
t	:	Thickness of the membrane (m)
Δt	:	Time interval (h)
ΔV	:	Volume change (L)
ΔP	:	Pressure change (bar)
π	:	Osmotic pressure (bar)
φ	:	Osmotic pressure coefficient
σ	:	Reflection coefficient,
ε	:	Porosity
β	:	van't Hoff coefficient
τ	:	Tortuosity

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